Developing a morphology-based Huff model using space syntax to analyse consumer spatial behaviour: A case study of Amman

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In this research, we propose developing a new Huff multi-attribute model combined with space syntax indices to draw upon the advantages of both models. The proposed Huff model will be morphology-based, able to outperform the traditional Huff model in explaining consumer spatial behaviour. In replacing geographic accessibility in the traditional Huff model, three types of distance were tested in the proposed graph-based model: topological, angular, and metric. Global choice was also added as an index. The regression results indicate that the proposed model noticeably outperforms the traditional Huff model. This will likely open the door to improvements in the two models, encompassing both explanatory and application aspects.

Keywords: Huff model, space syntax, morphology, shopping malls, Amman.
Thirdly (c), the number of predicting variables: Nakanishi and Cooper (1974) extended the model to include any number of variables rather than just two (size and distance) (Colomé, 2002; Wang, 2006). However, we think there is still room for improvement, especially through the introduction of space syntax as a new spatial model.

Space syntax, developed by Hillier and Hanson (1984), uses a set of new configurational graph-based techniques to analyse the local and global structure of the urban grids (Hillier and Hanson, 1984; Hillier et al., 1993). Space syntax adopted network techniques and analyses and applied them to the city. The aim of space syntax techniques is to understand the morphological logic of urban grids and to describe the morphological structure of urban areas in relation to certain activities (Hillier et al., 1993; Teklenburg et al., 1994), amongst which is shopping. Through its new definitions of space, space syntax has brought to light the regularities in the structures of the spatial networks of cities (Hillier, 2009). Space syntax is always introduced in opposition to the gravitational models, which have been seen as paying little attention to the network of the city, in order to present the significance of space syntax as a powerful morphological tool (Hillier and Penn, 1996). Space syntax has introduced new concepts of accessibility that are proven to be morphological and representative of observed movement patterns. These new motivating results were justified by introducing ‘natural movement’ (Hillier et al., 1993), ‘movement economy’ (Hillier, 1996), and ‘centrality’ theories (Hillier, 1999).

According to the natural movement theory, the main determinant of movement rates in different parts of a network will be a function of the structure of the network itself (Hillier et al., 1993). The theory of ‘the movement economy’ suggests that ‘natural movement’ initiates a process whereby areas with high movement rates will attract uses that are highly movement dependent, including retail and other uses, and this in return will attract more movement and so forth (Hillier, 1996). This suggests that urban configuration plays a crucial role in generating what have been called ‘live centres’; these are areas where movement dependent uses, like shopping, tend to concentrate (Hillier, 1999).

The previously introduced theories and space syntax techniques were applied in different studies analysing shopping activity including: the analysis of retail shop distribution (Campo, 2007); the study of the configurational properties of shopping centres to explain their social and economic differences (Sarma, 2006); the identification of the spatial signatures of suburban town centres (Vaughan et al., 2010); the study of the relationship between movement-seeking land uses, mainly retail, and spatial accessibility (Ortiz-Chao and Hillier, 2007); and the use of space syntax as a design support system for shopping centres (Teklenburg et al., 1994). The study of Sarma (2006), for example, demonstrated that both types of movement (to and through movement) - the two key measures of accessibility in space syntax - are related to the social logic of shopping. This suggests that in the case of community centres, in New Delhi, these two spatial variables are the critical variables in terms of the success or failure of the market. Similarly, Vaughan et al.’s (2010) study showed that through-movement, in this case taking account of the spatial model of Greater London, is evidently a reliable predictor of retail activity.

The advancements in recognising the regularities of the space were also accompanied by improvements in the definitions of distance in space syntax. While space syntax first used topological distance to define the space, other distance definitions were later added. Angular distance and even traditional metric distance were introduced as alternatives in the two key syntactic
accessibility measures used in space syntax. Topo-angular accessibilities presented more advantages in many practical studies.

2. Research outline

2.1 Goal

Although the two previously described models apparently work along separate lines, in this research we propose developing a new Huff multi-attribute model combining syntactic indices, so that the advantages of the two models can be realised. The proposed Huff model will be a morphology-based model, and thus able to outperform the traditional Huff model in explaining consumer spatial behaviour.

2.2 Significance

The significance of the study can be seen in:
- Combining the advantages of the two models used in analysing consumer spatial behaviour: the proposed Huff model is assumed to be sensitive to the morphology of the city and the configurational structure of its network.
- Building on this work, segment-graphs in space syntax can be proposed, through future research, to be the basis for applications of the proposed Huff model. Depending on these graphs, the applicability of the model can be substantially enhanced. This can include the use of segment-graphs for site-selection decisions.

3. Theoretical background

David Huff (1962) was the first to introduce the Luce axiom of discrete choice in the gravity model (Colomé, 2002). Thus, the model is based on the probability that an individual i selecting alternative j is proportional to the perceived utility of j relative to the sum of the utilities of all choices n that are considered by individual i (Huff, 2003). The utility of a store j was defined as the ratio of the square footage of selling area to the distance from a consumer’s residence i to the store j (Huff and McCallum, 2008). That is,

\[ P_{ij} = \frac{A_j^\alpha D_{ij}^\beta}{\sum_{j=1}^{n} A_j^\alpha D_{ij}^\beta} \]  
(Eq. 1)

\( \alpha \) and \( \beta \) are parameters (weights) of \( A_j \) and \( D_{ij} \), respectively, estimated based on actual survey data. The exponent for distance is assumed to be negative.

\( n \) is the total number of stores including store j.

Based on the work of Nakanishi and Cooper (1974), the Huff model was extended by including a set of store attractiveness attributes. The general form of the Huff model can be expressed as follows,

\[ P_{ij} = \frac{(\prod_{h=1}^{H} A_{hj}^{y_h}) D_{ij}^\lambda}{\sum_{j=1}^{n} (\prod_{h=1}^{H} A_{hj}^{y_h}) D_{ij}^\lambda} \]  
(Eq. 2)

\( A_{hj} \) is a measure of the hth characteristic \((h = 1,2,..,H)\) that reflects the attraction of facility;

\( y_h \) is a parameter for the sensitivity of \( P_{ij} \) associated with an attraction variable \( h \);

\( \lambda \) is a parameter for the sensitivity of \( P_{ij} \) with respect to accessibility (Huff and McCallum, 2008).

On the other hand, the space syntax model is based on a graphical representation of the actual urban layout, which is an objective description of its morphological structure. The urban grid is divided into axial lines, which are constructed by drawing the least set of the longest lines of sight that pass through all the spaces of the grid, such that all possible spaces are represented. The set of axial lines of an urban area is called the axial map (Hillier and Hanson, 1984; Hillier et al., 1993).
Mathematically, the network is translated into a graph in which lines are nodes and intersections are links, and configuration is measured through topological distances in the graph (Hillier et al., 1993; Hillier and Iida, 2005). In space syntax, the lines of the axial map are the elements of analysis. Properties of the lines are computed where a line is related to other lines in the axial map (Teklenburg et al., 1994). Thematic maps are often generated to represent the resulting values of the different analyses using different computer programs by colour banding these mathematical values.

Hillier et al. (1993) distinguished between two different types of analyses - ‘spatial integration’ and ‘spatial choice’ - and suggested that both are affected by the configuration of the urban grid. These correspond to closeness centrality, defined by Sabidussi (1966), and betweenness centrality, defined by Freeman (1977) - measures that are commonly used in network analysis. The two spatial variables can be defined in the global analyses as follows.

- Spatial integration: measures the distance from each spatial element to all others in a system (Hillier and Hanson, 1984; Hillier et al., 2012). It thus reflects the topological propensity for a node (axial line) to be a ‘destination’ of movement from all surrounding nodes in the graph. Mathematically, integration indicates the average distance that a node (or axial line) is from all other nodes in the urban system. The less average distance a node has, the more integrated (accessible) it is.

According to Hillier et al. (2012, p.156), ‘integration represents the to-movement potential of a space, and choice the through-movement potential, pointing out also that the two measures correspond to the two basic elements in any trip: selecting a destination from an origin (integration), and choosing a route, and so the spaces to pass through between origin and destination (choice)’. Previous studies proved some correlation between these two basic measures (integration and choice), at different scales, and retail agglomerations or rates of movement within these shopping centres or streets. These were seen as an indication that retail land uses take advantage of the opportunities offered by the passing movement or by being destinations themselves (Vaughan et al., 2010; Ortiz-Chao and Hillier, 2007; Hillier et al., 2012).

The distance between two nodes in the connectivity graph, which are two axial lines in an axial map, is measured in ‘step distance’, and also ‘step depth’. Step distance can be defined as the number of topological steps from a considered ‘origin’ node to another ‘destination’ node. Let (SD ij) be the shortest step distance between two points i and j in a connectivity graph representing an urban system. Accordingly, mean depth (MDi) for a node i is defined by:

\[ M_{Di} = \frac{\sum_{j=1}^{n} S_{Dij}}{n - 1} \]  
(Eq. 3)

where \( n \) is the number of nodes of a whole graph (Jiang et al., 2000). Integration (Ii) can be represented more simply by the following equation:

\[ I_i = \frac{1}{M_{Di}} \]  
(Eq. 4)
It is easy to show that integration is a kind of accessibility. The more integrated (accessible) nodes will be those which have the lowest value of mean distance.

With the development of the segment map, other distance types were applied in the graph analyses. Between two line segments, step distance is measured by one of three concepts: (a) least length (metric): distance of route is measured as the sum of segment lengths; (b) fewest turns (topological): distance is measured as the number of changes of direction that have to be taken on a route, which is similar to topological ‘step depth’ in the axial map; and (c) least angle change (angular): distance is measured as the sum of angular changes that are made on a route (Hillier and Iida, 2005). A common accessibility measure can then be based on the previous accessibility equation Eq.(4). The calculation of the step distance between pairs of nodes can be based on any of the three distance concepts in the segment-graph.

These three concepts of distance are different in terms of how people navigate and perceive the urban network. It has been found that people tend to take the least number of turns and the least angle change paths in their journeys from any origin to any destination. These last two types were tested by Hillier and Iida (2005) to be good representatives of people movement. In Barros et al.’s (2007) study, statistical results also indicated a strong association between the actual flow values and those obtained by the topological segment analysis. Empirical studies showed that ‘urban movement, both vehicular and pedestrian, are shaped far more by the [angular] and topological properties of the grid than by its metric properties’ (Hillier and Iida, 2005, p.475).

4. The proposed model

4.1 Why not the Huff model alone?

The gravitational models, in general, ignore the effects of urban morphology. These models pay little attention to the network configuration of the city and its related spatial effects. While space and movement within the city are seen as highly related to retail agglomerations and the success of shopping centres, the elements of space and movement are missed. Accessibility in gravity models is ‘a measure of the nearness of a place (area) or a point location approximating that place’ (Jiang et al., 1999, p.130). Jiang et al. referred to this as geographic accessibility (ibid). In some ways this is a rigid concept that treats the city as coarse-grained blank areas. The accessibility in this concept conceals the uniqueness of the city from any other city; that is, through its network configuration. However, in space syntax, accessibility refers to the connection of a line to the whole street network in the city. Measurement of this syntactic accessibility is applicable to a fine-scale urban structure at the street-level (Jiang et al., 1999).

4.2 Why not space syntax alone?

In space syntax, the spatial features are the only determinant of people’s movement to a place. For studying customers’ behaviour, that is not considered the appropriate method. People do not only go to shopping centres on the basis of spatial factors; they are also influenced by the attractions they offer, as traditional gravitational models propose. ‘As a matter of fact, from within this field, Space Syntax is likely to be regarded as nothing else than a special case of accessibility’ (Ståhle et al., 2005, p.131). Accordingly, using space syntax alone for modelling the spatial behaviour of consumers depending on accessibility measures is a one-dimensional process, as the attraction factor is missing.
4.3 Contribution of space syntax to the Huff model: A proposed model

We propose a combination of the Huff and space syntax models. This will be a Huff model in essence, including new spatial variables from space syntax, enabling spatial behaviour to be explained in terms of both attraction and distance in a probabilistic way. In addition, it will be possible to take the spatial configuration of the city into consideration. Thus, the benefits of both models can be obtained.

Consequently, space syntax can contribute to the Huff model as follows:

• **Firstly**: Replacing 'geographic accessibility' by 'syntactic' accessibility, the proposed model can be formulated to be morphology-based in performance, especially with the use of topo-angular accessibilities; i.e. the proposed model should be sensitive to the configuration of street network in the city and its spatial properties. It can also extend the proposed graph-based technique to test metric accessibility. We will then be able to recognise the difference between the performances of the three types of distance (topological, angular, and metric) in the proposed graph-based model. Despite the latter also being about physical accessibility, the technique is nevertheless different from the physical geographic accessibility measured from centroids of zones.

• **Secondly**: 'Global choice' in the proposed Huff model reflects the between-ness value of a mall location in the structure of a network. A shopping mall can benefit from the spatial properties of its location, as a natural destination in the city, or from being located on a street with huge passer-by movement.

4.4 The proposed model mathematical form

The proposed model will be formed to correspond to the segment-graph as a basis for the calibration of the model. In fact, space syntax models are generally not calibrated, which means no weights are assigned to distance whatever the type of the tested activity or behaviour. Calibration requires actual consumer data to estimate these weights. Whereas the amount of consumer data can be an issue depending on time and effort, we propose two methodologies for how space syntax concepts can be adopted and activated in the Huff model calibration.

Two levels of segmentation can be used, depending on the amount and scale of collected consumer data. (a) The nodal level: this is an ideal mode for syntactic calibration and application. Consumer data can be gathered at the node scale, where a node can be considered as one zone in the calibration. (b) The zonal level: the model can use a 'band of nodes' to estimate weights of attributes. The proposed model will retain its advantageous properties in terms of distance measurements, which will be explained in the next paragraphs.

Despite our use of the term 'zone', this has specific connotations that differ from other usages. A 'zone', in traditional geographic concepts, refers to one rigid unit, with no consideration given as to how the network is configured within it. However, a 'zone' in the proposed model will refer to group of nodes representing the street segments configuring the network within this zone; i.e. distance will be calculated in a syntactic way.

The proposed model can be expressed as follows, depending on the scale of segmentation.

**Working on node segmentation:**

Following the general form of the multi-attribute Huff model in Eq. (2), attributes of attractiveness can be extended to include additive indices in the proposed model as global choice ($C_j$). Moreover,
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Distance is replaced by step distance (SD\text{ij}).

The proposed equation will be applied for each node in the city as a consumer zone \(i\). \(P_{ij}\) is the probability of a consumer at a node \(i\) in the city system patronising shopping mall \(j\) located at another node in the system, and away from consumer \(i\) at step distance \(SD_{ij}\). \(SD_{ij}\) can be metric, topological, or angular:

\[
P_{ij} = \frac{(\prod_{h=1}^{n} A_{h_{ij}}^{\gamma}) (C_{j}^{\beta}) (S_{D_{ij}}^{\lambda})}{\sum_{j=1}^{n} (\prod_{h=1}^{n} A_{h_{ij}}^{\gamma}) (C_{j}^{\beta}) (S_{D_{ij}}^{\lambda})}
\]

(Eq. 5)

\(\gamma\) is a parameter (weight) associated with an attraction variable \(h\). \(\beta\) is a parameter of ‘choice for radius=n’, assumed to be positive\(^2\). \(\lambda\) is the exponent for step distance, assumed to be negative.

Working on zone segmentation:
At this level, the group behaviour of consumers is collected across a number of zones in the city, where the scale and number of these zones are dependent on time and available data. Thus, the distance measure should reflect the distance from a zone to a shopping mall. Traditionally, distance is taken from the centroid of the zone to a shopping mall, neglecting the configuration of the street network connecting the different nodes in the zone to that shopping mall.

The distance measure can reflect the distance from the zone based on the advantageous measures of space syntax in capturing configurational properties. This can be applied by taking the mean distance from all nodes in the zone to this shopping mall, which we term zonal mean distance. This should be a more reliable measure of distance from the zone that reflects the integration of the mall in relation to that zone system.

While distance is usually taken from a node at the node-segmentation level, here it is taken from a group of nodes constituting a zone at the zone-segmentation level. Zonal mean distance \((ZD_{ij})\) from consumer zone \(i\) to a shopping mall \(j\), is the sum of step distances from each node \(k\) in the zone to this shopping mall, divided by the number of nodes \(K\) constituting the zone subtracted by 1. Zonal mean distance can be either metric, topological, or angular:

\[
Z_{D_{ij}} = \frac{\sum_{k=1}^{K} S_{D_{kj}}}{K - 1}
\]

(Eq. 6)

The shopping mall can be inside or outside the zone. If it is inside the zone system, this is similar to mean depth in Eq. (3); however, the system here is zone nodes. If the shopping mall is outside the zone system, then \((K - 1)\) is replaced by \(K\).

Working on zonal segmentation, the model can be expressed as follows:

\[
P_{ij} = \frac{(\prod_{h=1}^{n} A_{h_{ij}}^{\gamma}) (C_{j}^{\beta}) (Z_{D_{ij}}^{\lambda})}{\sum_{j=1}^{n} (\prod_{h=1}^{n} A_{h_{ij}}^{\gamma}) (C_{j}^{\beta}) (Z_{D_{ij}}^{\lambda})}
\]

(Eq. 7)

Choice Rn values are extracted from global graph analysis, regardless of segmentation mode.

Notes:

\(^2\)‘Radius=n’ in space syntax refers to the global analysis, which means that for each node, analysis is done in relation to all nodes in the system.
Finally, we should note that after calibrating the model, the same level should be used, theoretically, in application so that no change in sensitivity of variables will happen due to change in the level of segmentation.

5. Methodology

In this paper we used the zonal level for calibration, although calibration at the nodal level is possible and can be tested in future research. The methodology includes three main steps to build the proposed model:

Step 1: Data collection and analysis. Different sets of data are required to carry out the proposed (Huff) model: destination (shopping malls) data, origin (zones) data, and interaction data. The latter indicates the patronage between a given origin and destination and the distance between them.

Step 2: Extracting space syntax indices. From space syntax analyses, the global spatial variables of choice and integration will be extracted to study the extent to which they respond to Amman’s morphology and to identify the differences between the three types of distance before using them in the model. It should be noted that investigating correlations between the syntactic measures and actual movement data is beyond the scope of this study. Afterwards, the segment map will be used to calculate the three types of distance matrices between all origins (zones) to all destinations (malls).

Step 3: Specification and calibration of the proposed model. Specification of the model involves identification of the different mall indices to be included. Three zonal mean distance alternatives (metric, topological, and angular) will be tested in the proposed model. After the model is specified, it can be calibrated to estimate

Figure 1:
Methodology for building and applying the proposed model
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the parameters (weights) of indices, so that the model has the best fit with actual data. We can also determine which variables are statistically significant and discriminatory in consumer choice decisions (see Figure 1).

6. Sample and data collection
The study takes Amman City as a case study, the biggest city and the capital of Jordan, where several shopping malls have been built in recent years. The competitive system in the study area contains 19 shopping malls distributed across the city, with different sizes and characteristics (see Figure 2).

To develop the proposed model, data was collected through survey, observation, and documentation. An online survey was designed and published using promotional advertisements on Jordanian websites. Two months after publishing the survey, 575 valid records have been obtained, which was the final size of the sample. Observations were carried out to count the number of visitors entering each mall. This was very important in order to validate the survey data. The correlation between ‘rates of visits to each mall as found in the survey’ and ‘the observed ones’ was found to be strong: R=.943 and R Square =.889. For each mall, the data for number of levels, number of stores, types of stores and goods, number of escalators and elevators, number of cinema seats, and number of parking lots and parking levels were collected. These data are very important as they will be used as physical indices of attractiveness in the model.

7. Space syntax analyses
An axial map of Amman was built according to the city’s network. Using Depthmap software
for analysis, choice and integration values for all axial lines were calculated and mapped. Figure 3 shows the global choice map. The highlighted ‘choice’ streets, which are the most used streets of the city, clearly coincide with the main streets in Amman. University Street, Airport Road, Medical-City Street, Zahran Street, Jordan Street, Istiqial Street, and other main streets can be easily recognised. To some degree this is an indication of the sensitivity of space syntax analyses to the morphology of the city.

It is also noticeable that most malls are located close to these ‘high-choice’ streets. We assume that the selection of mall locations was not arbitrary, but dependent on the apparent vehicular movement density in these main streets.

Depending on the segment map, segment colours range from pure black (for least mean distance) to pale grey (for most mean distance) (Figure 4). The maps, in other words, show the different integration analyses using the three types of distance. We can recognise the differences between these three types of distance that lie in their varying sensitivities to the structure of the network. Mean metric distance measures produce a ‘smooth concentric pattern from centre to edge’ (Hillier et al., 2007, p.5), forming ring shapes. Main streets of Amman cannot be recognised in metric analysis and are not found to be integrated streets. In metric analysis: the closer to the centre, the greater the integration. On the other hand, topological and angular analyses revealed some of the main important streets in Amman City; these are highlighted as more accessible, and thus more likely to be destinations for movement. Most of the malls are located on these integrated main streets.

These three graph analyses can be used to give a clear image of the differences in the distance concepts and how they will act when used in the proposed model. Using the proposed Huff model, the most successful mall, excluding the attractiveness attributes, will have the most accessible location with the least mean distance to all nodes. For topo-angular distance, the most successful mall would be much closer to main streets, whilst for metric it would be the one which is much closer to the middle of the city.
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Figure 4:
Integration analyses, using:
(a) metric,
(b) topological, and
(c) angular distances.

Figure 5:
Calculation of zonal mean distance (metric, for example):
Step distance values for all nodes comprising each zone were extracted and averaged for the zonal measurements.

\[ Z_{Dij} = \frac{\sum_{k=1}^{K} S_{Dij}}{(K - 1)} \]

\[ Z_{Dij} = \frac{16279283}{4592} = 3545 \text{ m} \]

\[ Z_{Bij} = \frac{23862280}{4539} = 5152 \text{ m} \]
Finally, three distance matrices were calculated between all origins (zones) to all destinations (malls): metric, topological, and angular. From each mall, step distance values for all nodes constituting each zone were extracted for the zonal measurements (Figure 5).

8. Specification and calibration of the model

Both the traditional Huff model and the proposed model will be developed to test whether using space syntax indices will improve the traditional model. Fifteen indices of attractiveness were included in the proposed model, in addition to choice Rn. One distance alternative was also used (zonal mean distance: metric, topological or angular). On the other hand, road metric distance from ‘centroid of zone’ and 15 indices of attractiveness were included in the traditional Huff model. Below are all the variables which will be used in the different specified models.

<table>
<thead>
<tr>
<th>Index</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric distance from centroid of zone</td>
<td>MetricCj</td>
</tr>
<tr>
<td>Zonal metric mean distance</td>
<td>MetricZj</td>
</tr>
<tr>
<td>Zonal topological mean distance</td>
<td>TopoZj</td>
</tr>
<tr>
<td>Zonal angular mean distance</td>
<td>AngZj</td>
</tr>
<tr>
<td>Gross leasable area (GLA)</td>
<td>A_1</td>
</tr>
<tr>
<td>Number of parking lots</td>
<td>A_2</td>
</tr>
<tr>
<td>Number of escalators &amp; elevators</td>
<td>A_3</td>
</tr>
<tr>
<td>Number of cinema seats</td>
<td>A_4</td>
</tr>
<tr>
<td>Entertainment area</td>
<td>A_5</td>
</tr>
<tr>
<td>Area of supermarket ‘food section’</td>
<td>A_6</td>
</tr>
<tr>
<td>Goods variance</td>
<td>A_7</td>
</tr>
<tr>
<td>Range of choice per branch</td>
<td>A_8</td>
</tr>
<tr>
<td>Appearance</td>
<td>A_9</td>
</tr>
<tr>
<td>Prices</td>
<td>A_10</td>
</tr>
<tr>
<td>Quality of goods and services</td>
<td>A_11</td>
</tr>
<tr>
<td>Number of fashion stores</td>
<td>A_12</td>
</tr>
<tr>
<td>Number of restaurants &amp; cafes</td>
<td>A_13</td>
</tr>
<tr>
<td>Number of leisure stores</td>
<td>A_14</td>
</tr>
<tr>
<td>Within shopping agglomeration</td>
<td>A_15</td>
</tr>
<tr>
<td>Global choice radius=n</td>
<td>C</td>
</tr>
</tbody>
</table>

Table 1: All indices and the corresponding symbols.

Then, the specified proposed model is formulated as,

$$ P_{ij} = \frac{A_{ij}^{\beta_{1}} + A_{ij}^{\beta_{2}} + A_{ij}^{\beta_{3}} + A_{ij}^{\beta_{4}} + A_{ij}^{\beta_{5}} + A_{ij}^{\beta_{6}} + A_{ij}^{\beta_{7}} + A_{ij}^{\beta_{8}} + A_{ij}^{\beta_{9}} + A_{ij}^{\beta_{10}} + A_{ij}^{\beta_{11}} + A_{ij}^{\beta_{12}} + A_{ij}^{\beta_{13}} + A_{ij}^{\beta_{14}} + A_{ij}^{\beta_{15}} + C_{ij}^{\beta_{16}} + Z_{Dij}^{\beta_{17}} + Z_{Aij}^{\beta_{18}}}{\sum_{j=1}^{n}[A_{1j}^{\beta_{1}} + A_{1j}^{\beta_{2}} + A_{1j}^{\beta_{3}} + A_{1j}^{\beta_{4}} + A_{1j}^{\beta_{5}} + A_{1j}^{\beta_{6}} + A_{1j}^{\beta_{7}} + A_{1j}^{\beta_{8}} + A_{1j}^{\beta_{9}} + A_{1j}^{\beta_{10}} + A_{1j}^{\beta_{11}} + A_{1j}^{\beta_{12}} + A_{1j}^{\beta_{13}} + A_{1j}^{\beta_{14}} + A_{1j}^{\beta_{15}} + C_{ij}^{\beta_{16}} + Z_{Dij}^{\beta_{17}} + Z_{Aij}^{\beta_{18}}]} $$

(Eq. 8)

where, $Z_{Dij}$ can be any of the three distance alternatives: Metric$Z_{ij}$, Topo$Z_{ij}$, or Ang$Z_{ij}$. The exponential function of decay of distance $\exp(-d^2/2\sigma)$ will be also used if it is found to be more representative of distance effect.

$\beta$: is a parameter (weight) for each index, which will be estimated in the calibration process.

Through calibration, we can determine which variables are significant and discriminatory when it comes to consumer choice decision. We can estimate the $\beta$ values for these significant parameters, which better reflect consumers’ sensitivities to change in attributes.

The traditional Huff model succeeded in explaining 0.486 of the variance in actual preferences using five indices: metric distance (from centroids), Gross Leasable Area (GLA), cinema seats, quality of goods and services, and number of fashion stores. These indices passed the significance test.

On the other hand, the three proposed models demonstrated strong correlation coefficients. Both metric and angular models managed to explain (659) of the variance, with four indices of attractiveness (GLA, cinema seats, quality of goods and services, number of fashion stores), and three indices of attractiveness (GLA, quality of goods and services, number of fashion stores), respectively.
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The topological model recorded higher R Square (.717), marking a noticeable distinction over the other two proposed models. Nevertheless, all three graph-based models were obviously better than the traditional Huff model in explaining the variance in consumers’ behaviour.

In replacing geographic accessibility in the traditional Huff model, three types of distance were tested in the proposed graph-based model: topological, angular and metric. Despite the latter also being a physical distance, we aimed to test metric measure in the new technique. Global choice of a mall’s location was added as an index in the model as well.

Through calibration of the proposed model, distance was shown as better represented by topological distance, which is perceived as the fewest turns (or visual steps) taken to reach the mall, in the exponential function for decay of distance. The proposed syntactic index choice Rn was not significant in any of the three proposed models. Nevertheless, choice Rn was included in some of the effective metric regression tests using different sets of variables. We assume that choice index will be more influential in the case of competition between small supermarkets or stores, where unplanned visits are more important.

Among the three types of distance, topological zonal mean distance was found to outperform the other proposed zonal metric and angular measures. However, topological zonal mean distance was expected to be much better than metric zonal mean distance. This is most likely because the city in our case study was segmented into relatively big zones or big ‘bands of nodes’. We assume that when segmentation becomes smaller, there will be more variance in the interactions between zones and malls, and thus the difference between the three types will be more obvious in calibration results.

9. Conclusion and discussion
While the Huff model constitutes one of the most widely used models for analysing consumer spatial behaviour, the space syntax concept of accessibility is evolutionary. Inclusion of these space syntax morphological features in the Huff model is proposed to improve the model’s performance.

Table 2: R, R Square results for the traditional Huff model and the three proposed models.

<table>
<thead>
<tr>
<th>The traditional Huff model</th>
<th>The proposed Graph-based models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metric</td>
</tr>
<tr>
<td>R = .697</td>
<td>R = .812</td>
</tr>
<tr>
<td>R Square = .486</td>
<td>R Square = .599</td>
</tr>
</tbody>
</table>

(Eq. 9)
traditional distance from the centroids of zones. Zonal mean distance measures were proposed to make calibrating the model possible, depending on the available consumer data. However, zonal mean distance, which is based on the segment map, adopted space syntax concepts of accessibility and can be considered as a special case of integration. This measure, even when using metric distance, outperformed traditional metric distance from the centroid of a zone in the interpretation of consumer spatial behaviour.

The big difference in the results of calibration between the traditional Huff model and the graph-based metric model can be explained as follows. (a) It is evident that greater inaccuracies in distance calculations in the traditional Huff model occurred when the destination (mall) was within the zone (Figure 6). In such cases, the mall can be located very close to the zone’s centroid, which gives a very short distance measure that does not represent the real distance of the mall from all households in the zone. In contrast, by calculating the distance from all nodes (street segments) constituting the zone, the mean distance gives a more accurate measure of the degree to which the mall is accessible and integrated into that zone. (b) Moreover, some zones have wide, empty, unpopulated areas; using centroids will therefore be misleading, depending on the geometry of the zone. Calculation of distance depending on the distribution of streets (nodes) avoids this problem as the pattern of nodes can be an indication of how houses are distributed in the zone.

In conclusion, the proposed model using topological accessibility proved far better than the traditional Huff model. The proposed model fits actual data better with $R^2=.717$. This is an improvement on the traditional model with $R^2=.486$. Moreover, when comparing the number of potential visitors for each shopping mall (estimated from the model) to the corresponding visitors (estimated from the survey), $R^2=.962$ for the proposed model, while $R^2=.755$ for the traditional Huff model (see Figure 7). Regression results indicate that the proposed model improves the traditional Huff model, whilst its explanatory performance is substantially enhanced.

We should note that node-segmentation is an ideal mode for calibrating the proposed model and its application, and is expected to be much more effective in relation to the model’s sensitivity to the morphology of urban space. It would be

![Figure 6: Calculating distance from 'Tlaa Al Ali' zone to Amman mall.](image)

(Left) The traditional metric distance from the centroid of the zone: 649 metres. (Right) The proposed metric zonal mean distance: 2,265 metres.
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Desirable for this to be investigated further at this level in future studies. On the applications side, the proposed model can open up more areas of applicability, especially with the use of the connectivity segment-graphs which are the basis of space syntax measurements. Street segments or nodes can be used as potential origins or destinations. That way, it is possible to develop more detailed probability surfaces and to find the optimal location for a new mall at the street-level. More work is also encouraged in this area.

Figure 7:
The estimated number of visitors to each mall from the survey in comparison to the estimated ones from the models:
(Left) The traditional Huff model, (right) the proposed model. The proposed model fits actual data better.

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